# Study of a Localized Meningococcal Meningitis Epidemic in Burkina Faso: Incidence, Carriage, and Immunity

**Judith E. Mueller,[1,a] Seydou Yaro,[2] Berthe-Marie Njanpop-Lafourcade,[1] Aly Drabo,[2] Régina S. Idohou,[1] Sita S. Kroman,[1] Oumarou Sanou,[1] Serge Diagbouga,[2,b] Yves Traoré,[3] Lassana Sangaré,[4] Raymond Borrow,[5,6] and Bradford D. Gessner[1]**

[1]Agence de Médecine Préventive, Paris, France; [2]Centre Muraz, Bobo-Dioulasso, [3]Université de Ouagadougou, and [4]Centre Hospitalier National Yalgado Ouédraogo, Ouagadougou, Burkina Faso; [5]Vaccine Evaluation Unit, Health Protection Agency, and [6]Inflammation Sciences Research Group, School of Translational Medicine, University of Manchester, United Kingdom

***Background.*** To better understand localized meningococcal meningitis epidemics, we evaluated a serogroup A (NmA) epidemic in Burkina Faso by surveillance, carriage, and seroprevalence studies.

***Methods.*** During March–April 2006, cerebrospinal fluid samples from patients suspected to have meningitis in 3 epidemic villages were analyzed by culture or polymerase chain reaction. We assessed meningococcal carriage and serogroup-specific serum bactericidal antibody titers with baby rabbit complement (rSBA) in a representative population sample (N = 624; age range, 1–39 years). A serogroup A/C polysaccharide vaccine campaign occurred in parallel.

***Results.*** Cumulative incidence of Nm meningitis was 0.45% and varied among villages (0.08%–0.91%). NmA carriage prevalence was 16% without variation by vaccination status. NmA carriage and anti-NmA seroprevalence varied by village and incidence. In the 2 villages with highest incidence and seroprevalence, presence of rSBA titers ≥8 was associated with NmA carriage (odds ratio [OR], 9.33 [95% confidence interval {CI}, 1.90–45.91]) and vaccination ≤4 days earlier (OR, 0.10 [95% CI, .03–.32]). Visibly purulent or Nm meningitis was significantly associated with recent flulike symptoms and exposure to kitchen smoke (risk ratios >15).

***Conclusions.*** A surge of NmA carriage may be involved in the development of meningococcal epidemics and rapidly increase anti-NmA seroprevalence. Flulike infection and kitchen smoke may contribute to the strength of epidemics.

The incidence pattern of bacterial meningitis in the African meningitis belt is characterized by ubiquitous hyperendemicity of meningococcal and pneumococcal meningitis during the dry season. Sporadic meningococcal epidemics occur in small areas and form epidemic waves every 7–10 years, which span larger regions or even several years [1].

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[a]Current affiliation: Department of Epidemiology and Clinical Research, Ecole des Hautes Etudes en Santé Publique, Rennes/Paris, France

[b]Current affiliation: Institut de Recherche en Sciences de la Santé, Bobo-Dioulasso, Burkina Faso

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Correspondence: Judith E. Mueller, MD, MPH, PhD, EHESP, Hôtel-Dieu, 1 place du Parvis Notre-Dame, 75181 Paris cedex 04, France (judith.mueller@ehesp.fr).

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Little attention is given to the fact that usually, within districts that declare an epidemic, high incidences are limited to a few health centers while others report case counts comparable to those of any dry season. Sié et al [2] described an epidemic due to serogroup A meningococci (NmA) in Burkina Faso during 2006, where most cases came from 1 health center, more precisely from 1 of the 20 villages served by this center. The epidemic strain was circulating in the larger region without epidemic and had previously been found in hyperendemic disease. The question arises which factors launch epidemics and which roles carriage and population immunity play.

Understanding localized epidemics is important for the prevention and control of epidemics of any meningococcal serogroup, especially in the context of evaluation of the impact of the NmA conjugate vaccine, which currently is being introduced in meningitis belt countries [3]. Toward this goal, we report a study of meningococcal meningitis incidence, carriage, and seroprevalence during a localized

NmA epidemic in Burkina Faso. We also explored correlates of protection against Nm meningitis in the epidemic context. Because the study coincided with a meningococcal A/C polysaccharide vaccine mass campaign, we also could evaluate the early impact of such vaccination on carriage and antimeningococcal antibody titers.

## METHODS

The sanitary district Secteur 15 in western Burkina Faso reported weekly incidence rates of up to 80 suspected bacterial meningitis cases per 100 000 inhabitants during February–March 2006. During this year, 2200 cases were reported in the district (0.57% of population), compared with 530 in 1997, and <250 per year during 2002–2005. The vast majority of cases were reported from 2 eastern areas in the district. The rural health centers Lena and Kofila in one of these areas and approximately 60 km east of Bobo-Dioulasso reported 20% of the district case count, although their population represented 3% of the district population. Reported weekly incidence rate were 200–1700 cases per 100 000 inhabitants during February–March, peaking in week 10 in Lena and week 11 in Kofila. Annual cumulative incidences were 1.9% in Lena and 6.1% in Kofila, compared with 7.4%, 1.1%, 1.0%, 0.7%, 0.6%, 0.3%, and 0.1% in the 7 neighboring health centers situated within a distance of 20 km.

During calendar weeks 10–17 (March–May), we provided diagnostic assistance to the health centers of Lena and Kofila. In accordance with national guidelines, the majority of suspected meningitis patients underwent lumbar puncture. The nurses in charge were asked to send all cerebrospinal fluid (CSF) samples for culture and polymerase chain reaction (PCR) analysis to Centre Muraz, Bobo-Dioulasso, to identify meningococci (including genogroup), pneumococci, or *Haemophilus influenzae* [4].

In addition, we examined a representative sample of healthy residents aged 1–39 years in 3 villages served by the health centers Lena and Kofila (Figure 1). From 10 villages attending the 2 health centers (10 700 inhabitants), we selected 3 villages on the basis of residence of patients with reported meningitis cases and population size. Lena (4640 inhabitants equally distributed among Muslims and Christians) is located 7 km from the main road linking Bobo-Dioulasso to Ouagadougou and is headquarters of the departmental administration. Kofila (2600 predominantly Muslim inhabitants) is situated 5 km from Lena with 2 access routes, 1 of which goes through Lena. Konkourouna (1660 predominantly Christian inhabitants) is accessible only through Kofila (3 km).

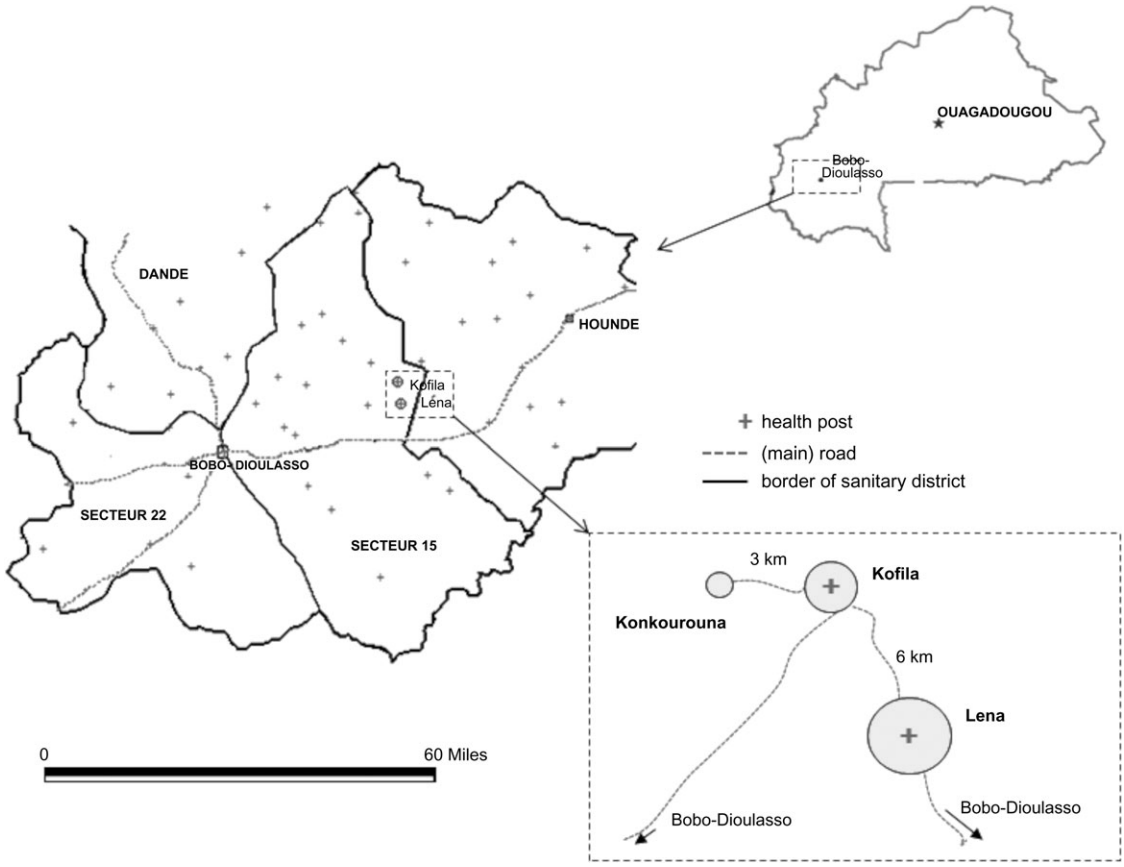


**Figure 1.** Geographic map of Burkina Faso, sanitary district Secteur 15, and the study villages of Lena, Kofila, and Konkourouna.

The study was approved by the Ethics Committee of Centre Muraz. Participants were selected by 2-stage cluster sampling using village quarters and compounds as clusters, sampling to equal parts in 4 age groups (1–4, 5–9, 10–19, and 20–39 years). Selected persons (or their legal guardians if minors) provided written informed consent for participation and were invited to the study visit the following day at a central place in the village.

The study visits took place during March 13–28 (weeks 11–12). Information on sociodemographic and vaccination status, personal and family medical history, and living conditions was collected on standardized questionnaires. A mass campaign with meningococcal serogroup A/C polysaccharide vaccine targeting the 2- to 30-year-old population was conducted on March 12–15. Whereas most participants from Konkourouna were examined before the vaccine campaign, most participants from Kofila and Lena were examined 1–2 weeks after. For <10-year-old children, mid-upper arm circumference (MUAC) and height were measured in a standardized way. Malnutrition was defined as MUAC-for-height less than 2 standard deviations below the mean [5]. Pharyngeal swab samples were taken via the mouth, immediately plated on selective chocolate agar media, and immediately incubated. For bacteriological analyses of swab samples, up to 3 colonies per plate were analyzed by means of biochemical tests and PCR. Meningococcal carriage isolates were sero(sub)typed by means of standard methods and genotyped by means of pulsed-field gel electrophoresis (PFGE) as described elsewhere [6].

Blood was collected, centrifuged, and aliquoted on site and stored at 8°C for <3 hours until freezing. Serum samples from participants who had not recently been vaccinated or who received vaccine ≤4 days prior to the blood draw were tested by means of serum bactericidal antibody assay against serogroups A and W135 using baby rabbit complement (rSBA) [7]. The reference strains were F8238 (A:4:P1.20,9) for NmA and M,01.0240070 (W135:NT:P1.18–1,3) for NmW135.

In June 2006, the occurrence of suspected meningitis after the study visit was retrospectively assessed among all study participants and confirmed by review of health center and laboratory registries.

Statistical analyses were performed on Stata version 10 software, using standard epidemiological methods, accounting for design effect. Meningitis incidences were estimated for suspected cases (definition entirely based on clinical symptoms [8]), visibly purulent cases (if CSF was turbid upon puncture), and Nm cases (if positive result in PCR or culture analysis of CSF). Cumulative incidences and weekly incidence rates were calculated as number of cases identified during the surveillance period (calendar weeks 10–17) and during a given week, respectively, divided by the population size as provided by sanitary authorities. Recent users of antibiotics were excluded when estimating carriage prevalence. Using logistic regression with forward stepwise variable selection to obtain multiply adjusted odds ratios (ORs) and 95% confidence intervals (CIs), we evaluated the role of self-reported flulike symptoms during the 2 previous months and exposure to kitchen fire smoke (>1 hour/day) as predictors of visibly purulent or Nm meningitis among the study participants, including only cases that occurred after the study visit in the village of Konkourouna. In the same way, we evaluated determinants of putatively protective rSBA titers and serological correlates of protection by estimating the risk ratio of meningitis at various cutoffs of rSBA titers among unvaccinated individuals. Odds ratios or risk ratios with 95% CIs not including the Null were considered statistically significant.

## RESULTS

### Surveillance

During calendar weeks 10–17, 310 cases of suspected meningitis were recorded. Lumbar puncture and CSF aspect were documented in 91%, and for 54% (n = 167), CSF samples were received at Centre Muraz. PCR results were available for all cases and culture results for 89 cases (29%). For both tested and untested cases, about half had visibly purulent and one-third clear CSF. CSF was clear in half and visibly purulent in one-third of PCR-negative cases. The case fatality proportion was 5% for all Nm cases and 1% for suspected cases with confirmed etiology. In total, 19% of cases were confirmed NmA (n = 24), nongroupable Nm (n = 6), or pneumococcus (n = 1). Of 17 NmA and nongenogroupable meningococcal isolates tested, all were characterized as phenotype A:4:P1.9 and sequence type ST-2859, clonal complex ST-5.

The cumulative incidence of suspected and Nm meningitis during weeks 10–17 was highest in Konkourouna, with 6.34% suspected meningitis (95% CI, 5.27%–7.68%) and 0.91% Nm meningitis (95% CI, .52%–1.49%), followed by Lena with 2.89% suspected meningitis (95% CI, 2.44%–3.41%) and 0.28% Nm meningitis (.15%–.48%) and Kofila with 2.69% suspected meningitis (95% CI, 2.10%–3.39%) and 0.08% Nm meningitis (95% CI, .01%–.28%). The peak weekly incidence rate of Nm meningitis during the study period was highest in Konkourouna (724 cases per 100 000 [95% CI, 375–1261 cases]), followed by Lena (194 cases per 100 000 [95% CI, 89–368 cases]), and lowest in Kofila (38 cases per 100 000 [95% CI, 1–214 cases]), where the peak in suspected cases occurred with some delay (Figure 2). No Nm meningitis was confirmed from calendar week 14 on, 3 weeks after mass vaccination and about 7 weeks after the epidemic started. For 308 suspected meningitis cases with age information, the cumulative incidence during weeks 10–17 was 5.19% in <1-year-old infants, 10.35% in 1- to 4-year-old children, 2.65% in 5- to 19-year-olds, and 0.75% in ≥20-year-old persons. For 30 Nm meningitis cases with age information, the cumulative incidence during weeks 10–17 was 0% in <1-year-old infants, 0.58% in 1- to 4-year-old children, 0.41% in 5- to 19-year-olds, and 0.07% in ≥20-year-old persons. The age groups of 1- to 4-year-old children and 5- to 19-year-old persons each contributed 40% to all suspected cases and 23% and 67%, respectively, to Nm meningitis.

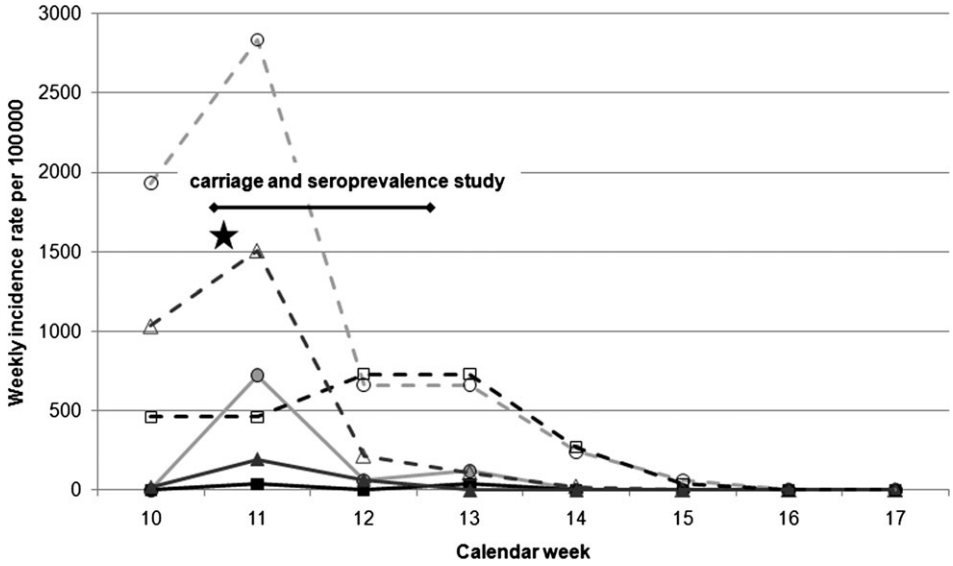


**Figure 2.** Weekly incidence rates of suspected (*dotted lines, empty symbols*) and confirmed (*solid lines, filled symbols*) meningococcal meningitis cases, during a localized epidemic due to meningococcal serogroup A in western Burkina Faso, March–April 2006, by village. *Black and squares,* Kofila; *dark gray and triangles,* Lena; *light gray and circles,* Konkourouna. *Star,* timing of meningococcal group A/C polysaccharide vaccine mass campaign.

### Carriage and Seroprevalence Study

We included 624 participants, with blood samples insufficient for 2 children. Substantial differences between the villages were observed regarding school attendance, number of persons in bedroom, exposure to kitchen smoke, meningococcal vaccination before 2006, prevalence of upper respiratory tract infection and malnutrition, and report of meningitis cases among participants and their family (Table 1). In Konkourouna, 46% of the 2- to 30-year-old participants reported vaccination during the recent campaign. In the 2 villages where the campaign was completed before the study visits (Kofila and Lena), vaccine coverage in the target age group (2–30 years) was 97.7% (95% CI, 96.2%–99.2%). Coverage was 50.0% (95% CI, 28.4%–71.6%) among 1-year-old children and 91.1% (95% CI, 83.4%–98.8%) among 31- to 39-year-old persons.

In the following June, meningitis during the 2006 dry season was reported for 34 of 624 (5.4%) participants, 25 (4.0%) with lumbar puncture and none with fatal outcome. For 18 participants, a health center registration was found, 13 with documentation of lumbar puncture and 9 with visibly purulent CSF. NmA was confirmed for 3 participants, whereas for 5, a final diagnosis other than meningitis, mainly malaria, was documented. The cumulative incidence in this cohort (March–June) was 0.48% for Nm meningitis and 1.60% for visibly purulent/Nm meningitis. Most of the cases occurred before the study visit in Lena, and after in Konkourouna and Kofila.

Flulike symptoms were strongly associated with subsequent visibly purulent/Nm meningitis (bivariate data in Table 1; crude OR, 3.24 [95% CI, .41–25.70]; adjusted for age group, sex, vaccination status, NmA carriage, and kitchen fire smoke: OR, 16.11 [95% CI, 1.28–203.33]). Exposure to kitchen fire smoke was itself a strong risk factor (bivariate data in Table 1; crude OR, 7.30 [95% CI, .75–70.58]; adjusted for age group, sex, vaccination status, NmA carriage, and flulike symptoms: OR, 26.34 [95% CI, 4.49–154.46]).

Adjusting for age group, sex, and NmA carriage, the relative risk for visibly purulent/Nm meningitis was OR, 7.68 (95% CI, .43–138.33) at an rSBA cutoff of ≥8; OR, 3.87 (95% CI, .69–21.60) at ≥512; and OR, 0.42 (95% CI, .06–2.84) at ≥1024 (Figure 3).

Meningococci were isolated from 134 of 624 (21.5%) participants. The majority of participants carried NmA (n = 94), followed by NmY (n = 37), and NmNG (n = 3). The age-standardized Nm carriage prevalence was 22.5%, with NmA 16.2%, NmY 6.0%, and non-genogroupable Nm 0.4%. NmA carriage prevalence was similar among vaccinated and unvaccinated participants (19% vs 28% in Konkourouna, 7% vs 0% in Kofila, and 19% vs 11% in Lena). The difference in carriage prevalence between villages was seen in all age groups, whereas age distribution (Figure 4) did not vary by village. As an exception to this, in villages with high carriage prevalence (Lena and Konkourouna), but not in Kofila, NmA carriage prevalence was substantially higher among 1-year-old children than among 2- to 4-year-old children (23% vs 6%; $P = .055$).

Sero-(sub)typing and PFGE was performed on 148 meningococcal isolates from 88 carriers, and 34 underwent multilocus sequence typing. The results comprised A:4:P1.9 of ST-2859 (clonal complex ST-5; n = 100), Y:14:P1.5,2 of ST-4375 (clonal complex ST-23; n = 47), and NG:NT:NST of ST-192; n = 1). NmA isolates showed 4 different PFGE profiles, 1 single profile holding 87% of isolates. NmY isolates showed 7 different profiles, 1 single profile holding 55% of isolates (data not shown). From 42 participants, 2 or 3 Nm isolates were tested. Serogroup, serotype, and genotype

**Table 1. Participant Characteristics in a Representative Sample of Village Residents Aged 1–39 Years in Western Burkina Faso, 2006[a]**

| Characteristic | Kofila (n = 203) | Lena (n = 316) | Konkourouna | | |
|---|---|---|---|---|---|
| | | | Total (n = 105) | With meningitis (n = 7) | Without meningitis (n = 92) |
| Age, mean years (SD) | 13.0 (10.2) | 13.3 (10.8) | 12.6 (10.2) | 8.6 (9.8) | 13.2 (10.4) |
| Female sex | 109 (53.7) | 162 (51.3) | 58 (55.2) | 3 (42.9) | 53 (57.6) |
| Ever school visit (age >5 years) | 89 (58.6) | 173 (76.4) | 21 (30.9) | 2 (30.0) | 18 (66.7) |
| Exposed to kitchen fire smoke (>1 hour/day) | 49 (24.4) | 79 (25.0) | 43 (41.8) | 5 (83.3) | 37 (40.7) |
| Sharing bedroom with >4 persons | 53 (26.4) | 65 (20.7) | 42 (40.0) | 2 (28.6) | 37 (40.2) |
| Recent meeting attendance >10 persons | 43 (21.3) | 32 (10.2) | 24 (23.1) | 1 (14.3) | 21 (23.1) |
| Malnutrition (age <9 years) | 9 (9.1) | 34 (21.5) | 13 (24.5) | 1 (16.7) | 10 (23.3) |
| Meningococcal vaccination before 2006 | 23 (16.6) | 104 (33.0) | 2 (2.0) | 0 | 2 (2.3) |
| Recent meningococcal vaccination[b] | 193 (95.1) | 298 (94.3) | 48 (45.7) | 1 (14.3) | 46 (50.0) |
| Recent antibiotic use | 0 | 7 (2.4) | 0 | 0 | 0 |
| Recent meningitis case in family | 25 (12.3) | 49 (15.5) | 37 (35.2) | 3 (42.9) | 30 (32.6) |
| Self-reported recent meningitis | 3 (1.5) | 10 (3.2) | 5 (4.8) | … | … |
| Self-reported symptoms, past 2 months | | | | | |
| Flulike symptoms | 26 (13.2) | 37 (11.9) | 14 (13.5) | 2 (28.6) | 10 (11.0) |
| Difficulty breathing | 9 (4.4) | 18 (5.7) | 20 (19.1) | 1 (14.3) | 15 (16.3) |
| Sore throat | 15 (7.4) | 58 (18.4) | 17 (16.2) | 0 | 15 (16.3) |
| Productive cough | 83 (40.9) | 186 (58.9) | 45 (42.9) | 2 (28.6) | 39 (42.4) |
| Any ENT symptoms observed[c] | 46 (22.7) | 126 (40.0) | 48 (45.7) | 3 (42.9) | 40 (43.5) |
| NmA carriage | 13 (6.4) | 58 (18.8) | 23 (21.9) | 2 (28.6) | 19 (20.7) |
| Serogroup A rSBA titer ≥8 | 26 (25.0) | 13 (68.4) | 52 (50.5) | 6 (85.7) | 41 (45.6) |

Abbreviations: ENT, ear, nose, and throat; rSBA, serum bactericidal antibody using rabbit serum; SD, standard deviation.

[a] Data are reported by village and by subsequent visibly purulent or confirmed serogroup A meningococcal meningitis (in Konkourouna and participants not reporting previous meningitis only). Data are no. (%) of individuals unless otherwise specified.

[b] Self-reported meningococcal A/C polysaccharide vaccination during the mass campaign conducted in parallel to the study.

[c] Observed during the ENT exam for swabbing.

were identical within each participant, but in 4 NmA and 4 NmY carriers, 2 different PFGE profiles with 1 band difference were identified.

Seroprevalence of NmA rSBA titers ≥8 in unvaccinated individuals differed substantially between villages, with Konkourouna and Lena showing higher seroprevalence (68% on average) than Kofila (20%), the village located in between (test for difference between villages, $P = .001$; Figure 5*A*). By contrast, among recently vaccinated individuals, seroprevalence was low (28%) and homogeneous among villages, and showed a relatively flat age distribution. The same was observed for the seroprevalence of rSBA titers ≥1024 and geometric mean titres (GMT) (Figure 5*B* and *C*). The seroprevalence of NmW135 rSBA titers ≥8 was low (<20%) and varied little by vaccination status or village, whereas it increased continuously with age (Figure 5*D*).

In multivariate analyses, in villages with highest NmA carriage prevalence (Konkourouna/Lena), NmA rSBA titers of ≥8 were significantly associated with NmA carriage (OR, 9.33), age groups 5–9 years (OR, 7.64 vs 1- to 4-year-olds) and 10–19 years (OR, 4.65 vs 1- to 4-year-olds), and meningococcal vaccination during the previous 4 days (OR, 0.10; Table 2). No difference was observed between villages for determinants of rSBA titer ≥1024, which was associated with carriage of NmA and NmY and age 5–9 years to similar extent (OR, ~4;), but the association was significant (95% CI did not include the Null) only for NmA carriage and age. NmW135 rSBA titers ≥8 were significantly associated with NmY carriage (OR, 4.64) and age groups 10–19 years (OR, 3.89 vs 1- to 4-year-olds) and 20–39 years (OR, 6.25 vs 1- to 4-year-olds). The inclusion of malnutrition in the models for <9-year-old children did not explain seroprevalence against any serogroup (data not shown).

## DISCUSSION

During this Nm meningitis epidemic in western Burkina Faso, we found high incidences with up to 10% of children undergoing lumbar puncture for suspected meningitis. Cumulative incidence of Nm meningitis was up to 0.9%, which is an underestimate, because our surveillance started just before the peak of the epidemic, CSF specimens were tested for only about half of suspected cases, and culture and multiplex PCR testing in Burkina Faso has been reported to have only 31% sensitivity compared with nested PCR testing in a European reference laboratory [9]. Taking into account these elements, the cumulative incidence of Nm meningitis during this epidemic may have been around 4%. Incidences varied substantially among the health centers and study

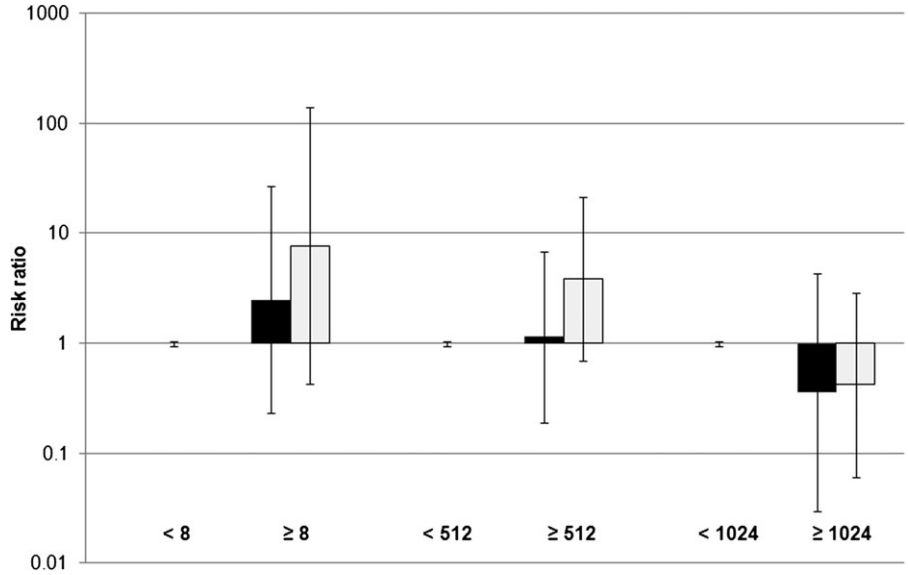


**Figure 3.** Risk ratio of visibly purulent or confirmed Nm meningitis at various cutoffs (≥8, ≥512, and ≥1024) of anti-A serum bactericidal antibody titers during a localized epidemic due to meningococcal serogroup A in western Burkina Faso, 2006, among 99 unvaccinated individuals in Konkourouna. Risk ratio and 95% confidence intervals (*error bars*) are crude (*black*) and adjusted for age group, sex, and serogroup A carriage at serological assessment (*gray*).

villages. This observation underlines the importance of analyzing surveillance data at the health center level to fully understand the epidemic process and even to target epidemic control activities.

As a hypothetical interpretation, the difference in incidence, carriage, and seroprevalence among the 3 villages may be explained as follows: in the early phase of the epidemic, Kofila (the village with lowest incidence, situated in the middle) was protected by some unkown factor, which kept NmA carriage and transmission, and in consequence incidence, low. NmA seroprevalence in this village also remained relatively low, as the stimulus from NmA carriage lacked. Later on, this protective factor waned, NmA transmission increased, and Kofila would have become epidemic (as the slightly rising incidence of suspected cases suggests), when vaccination became effective in time to stop the process. This explanation is hypothetical, but our observation suggests in any case that high carriage prevalence is needed for an epidemic to occur. The epidemic strain had been isolated from meningitis cases throughout the Bobo-Dioulasso region since 2003 during nonepidemic conditions [10] while being rarely found in carriage ([11, 12, 13]). The possibility cannot be

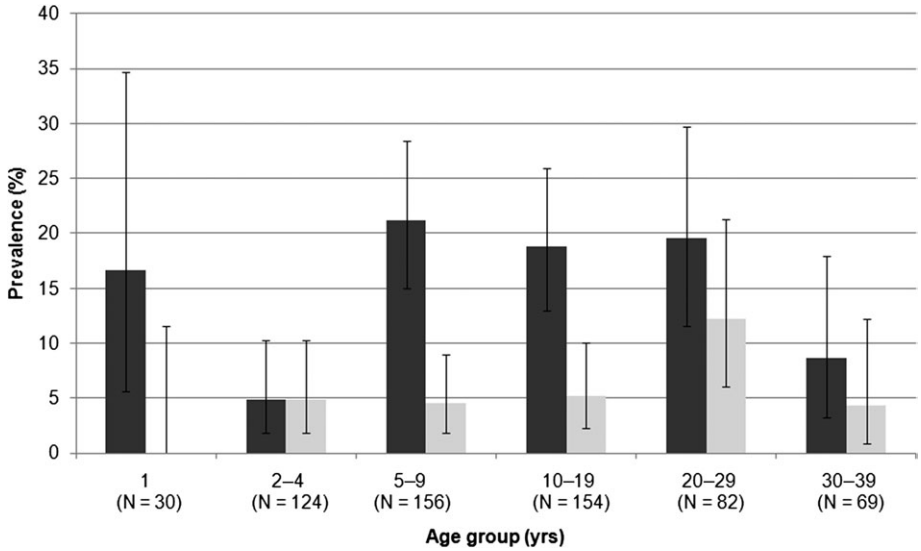


**Figure 4.** Prevalence of serogroup A (*dark gray*) and serogroup Y (*light gray*) meningococcal carriage by age groups in the general population during a localized epidemic due to meningococcal serogroup A in western Burkina Faso, 2006. Error bars are 95% confidence intervals.

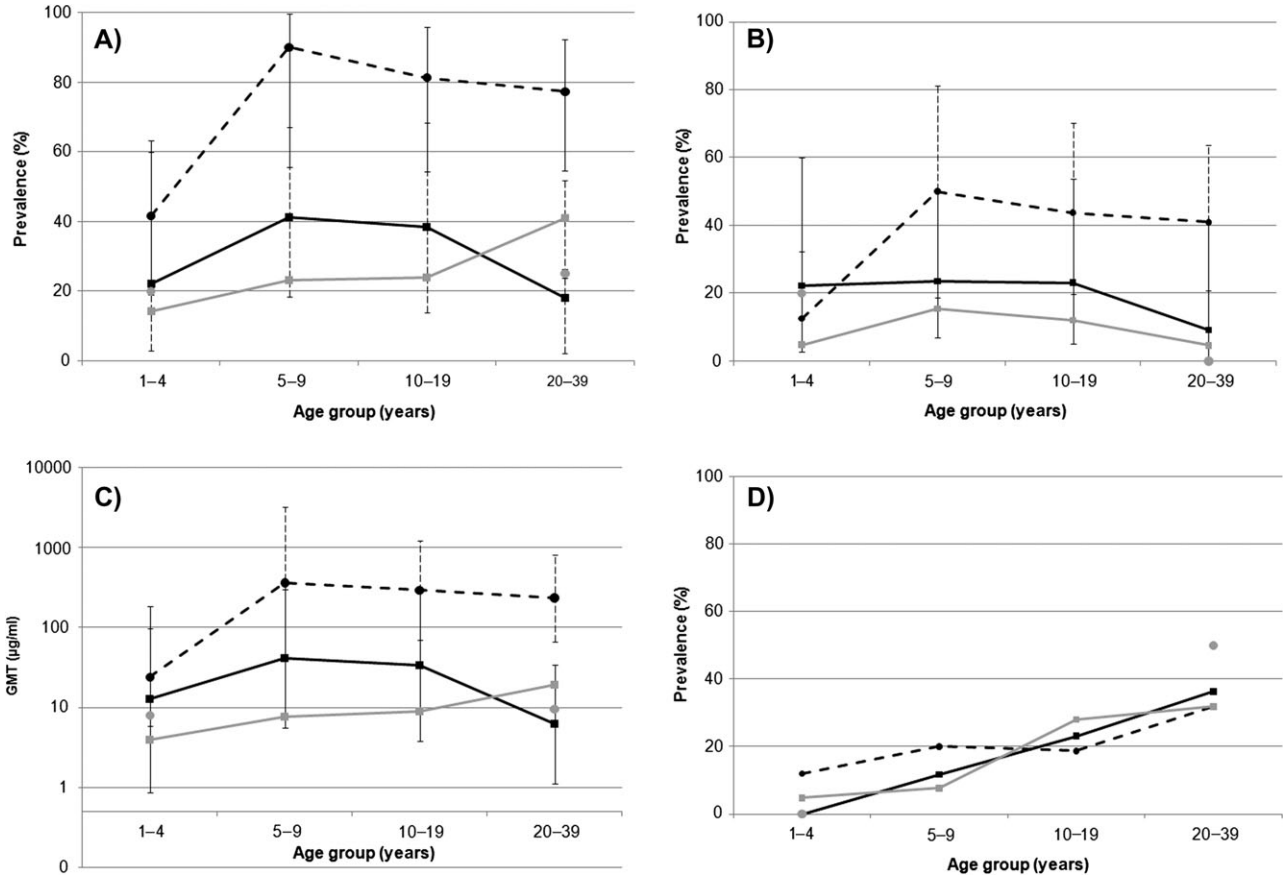


**Figure 5.** Age-specific serum bactericidal antibody titers against meningococcal serogroups A and W135, by village and vaccination status in the general population during a localized epidemic due to meningococcal serogroup A in western Burkina Faso, 2006. *Black*, Konkourouna and Lena, villages with high incidence and serogroup A carriage (n = 122). *Gray*, Kofila, village with relative low incidence and low serogroup A carriage (n = 33). *Solid line and squares*, vaccinated individuals; *dotted line and circles*, unvaccinated individuals. Error bars are 95% confidence intervals in Konkourouna and Lena. Included are only unvaccinated individuals or those with meningococcal polysaccharide A/C vaccination up to 4 days earlier. The number of eligible serum samples was insufficient for statistical analysis among unvaccinated persons of age 5–19 years in Kofila. *A*, Seroprevalence of anti-A titers ≥8. *B*, Seroprevalence of anti-A titers ≥1024. *C*, Geometric mean anti-A titers. *D*, Seroprevalence of anti-W135 titers ≥8.

excluded that the epidemic strain differed from the hyperendemic strain below pheno- and genotype. The great instability of meningococci is demonstrated by the finding of 4 different PFGE profiles in NmA isolates from the same carrier. These mutations may have occurred during carriage or, less likely, during culture.

To explain the surge in NmA carriage during epidemics, we previously hypothesized that some additional highly localized factor could be involved—we suggested viral respiratory tract infections [14]. This hypothesis was based on the association of NmA carriage with upper respiratory tract infection (URTI) symptoms reported earlier from this study [15]. The presented additional finding of a strong prospective association between flulike symptoms and visibly purulent/Nm meningitis provides new force to this hypothesis. URTI symptoms did not predict disease, but their prevalence correlated with disease incidence across villages. Flulike symptoms did not predict carriage, and their prevalence did not correlate with incidence across villages. In combination, this could indicate that widespread URTI increases NmA circulation in the population, whereas flulike disease puts individuals at risk for meningitis. The surprisingly high prevalence of URTI symptoms in our study requires additional evaluation with regard to seasonality and health impact.

Exposure to kitchen fire smoke already has been described as a risk factor for meningitis in Ghana [16]. This possibly corresponds to facilitated invasion of meningococci via smoke-damaged mucosa, reinforcing the noxious effect of dry climate [14].

Although limited by small sample size, subsequent vaccination, and probable impact of intensive NmA circulation on rSBA titers, our serological data provide some evidence for a correlate of protection in the epidemic context. The cutoff NmA rSBA titer of ≥1024 would be substantially higher than established correlates of protection, for example, against NmC in the UK population (rSBA titer ≥8) [17]. Hypothetical explanations include differences between serogroups, avidity of natural versus vaccine-induced antibody, and population or environmental characteristics influencing effective protection by serum antibodies (hypothesis of

**Table 2. Determinants of Serum Bactericidal Antibody (SBA) Titers ≥8 Against Meningococcal Serogroups A and W135 in the General Population During a Localized Epidemic Due to Meningococcal Serogroup A in Western Burkina Faso, 2006[a]**

| Characteristic | SBA anti-A (≥8) | | SBA anti-A (≥1024), all villages | SBA anti-W135 (≥8), all villages |
|---|---|---|---|---|
| | Lena and Konkourouna | Kofila | | |
| Serogroup carriage | | | | |
| A | 9.33 (1.90–45.91) | 1.67 (.48–5.81) | 3.96 (1.60–9.82) | 1.68 (.75–3.76) |
| Y | 4.15 (.67–25.54) | 0.97 (.16–5.90) | 3.69 (.88–15.41) | 4.64 (1.33–16.18) |
| Age, years | | | | |
| 1–4 | 1 | 1 | 1 | 1 |
| 5–9 | 7.64 (2.62–22.54) | 1.52 (.28–8.44) | 4.21 (1.30–13.68) | 1.88 (.60–5.93) |
| 10–19 | 4.65 (1.30–16.70) | 1.49 (.48–4.55) | 2.78 (.90–8.56) | 3.89 (1.40–10.83) |
| 20–39 | 2.85 (.85–9.60) | 3.27 (.68, 15.86) | 1.55 (.50–4.83) | 6.25 (1.76–22.17) |
| Recent vaccination[b] | 0.10 (.03–.32) | 1.48 (.19–11.73) | 0.48 (.20–1.17) | 0.91 (.36–2.30) |
| Sex[c] | 1.05 (.49–2.25) | 1.11 (.38–3.27) | 1.42 (.67–3.01) | 1.16 (.54–2.52) |
| Village | | | | |
| Konkourouna | … | … | 1 | 1 |
| Kofila | … | … | 0.53 (.20–1.36) | 0.92 (.37–2.31) |
| Lena | … | … | 2.98 (.96–9.28) | 0.66 (.18–2.39) |

[a] Included are only unvaccinated individuals or those with meningococcal polysaccharide A/C vaccination up to 4 days earlier. Data are odds ratio (95% confidence interval).

[b] Self-reported meningococcal A/C polysaccharide vaccination during the mass campaign conducted in parallel to the study.

[c] Sex is referent to males.

direct nasomeningeal invasion of meningococci during the dry season in the African meningitis belt [14, 18]). To increase the number of observed cases, we used visibly purulent/Nm meningitis as outcome, which appears justified as all but 1 confirmed cases were due to NmA. Individuals could have acquired NmA carriage or been vaccinated after the study visit, which may have altered their rSBA titers. However, all cases but 1 occurred within 1 week after the blood draw; therefore, vaccination following the visit unlikely would have provided protection.

In high-carriage villages, NmA carriage was strongly associated with NmA rSBA titers ≥8 and to a lesser degree with titers ≥1024, suggesting that NmA carriage induces some serogroup-specific immunity, whereas high titers are determined in addition by other factors. As both NmA and NmY carriage were associated with rSBA titers ≥1024 to a similar extent in all 3 villages (NmY carriage not significantly, possibly due to fewer carriage events), carriage of other meningococcal serogroups could contribute to high titers via noncapsular elements of the bacterium.

Seroprevalence against W135 was similar to findings in Bobo-Dioulasso in 2003 [12]. This is surprising, as in contrast to 2003, we did not find any NmW135 carriage, which may have been absent from the population for several years. The high NmY carriage prevalence in this study possibly contributed to NmW135 immunity, as suggested by the positive association between NmY carriage and NmW135 rSBA titers. The capsular sero(sub)type of the NmY carriage strains (14:P1.5,2) differed from that of the NmW135 strain used for rSBA (NT:P1.18–1,3), such that other minor antigens would play a role in this cross-reacting immunity.

Some findings are relevant for vaccine prevention. First, the observed age distribution of NmA carriage and incidence argues for conjugate vaccination during the first year of life and up to at least 29 years, to optimize indirect protection from the vaccine strategy. However, despite the NmA conjugate vaccine introduction targeting the 1- to 29-year-old population, substantial NmA transmission among older age groups may occur as soon as epidemiogenic factors are present.

As previously described for *H. influenzae* type b vaccines [19–21], meningococcal polysaccharide vaccine seems to diminish NmA rSBA titers during the first days following vaccination. This effect could be caused by an initial decrease in free immunoglobulin G antibody in response to antigen presentation. Interestingly, the difference between vaccinated and unvaccinated persons in our study was only seen in the 2 villages with intense NmA circulation and high rSBA seroprevalence. The clinical relevance of this rSBA reduction is not clear. An incidence reduction, not increase, was observed during the week following the mass campaign, but the small sample size does not allow this question to be evaluated.

The reported data do not show any impact of polysaccharide vaccine on NmA carriage during the first days after vaccination, which is in concordance with a recent systematic review [22]. Finally, the high vaccine coverage among age groups outside the vaccination target is of importance for vaccination operations, as additional doses are required to achieve high coverage in the target population.

In summary, this evaluation of an NmA epidemic documented a high burden of disease in individual health centers and villages,

showed high carriage prevalence of the outbreak strain in all age groups, demonstrated great variability of carriage and immunity within a small geographical zone during the epidemic, provided some evidence for an implication of URTI and flulike disease in the epidemic process, and suggested rSBA titers ≥1024 as correlate of protection against epidemic NmA disease. Other serogroups, particularly NmW135 and NmX, have epidemic potential in sub-Saharan Africa ([23, 24, 25]), and the observations from an NmA epidemic will increase our understanding of meningococcal epidemiology after the introduction of NmA conjugate vaccine.

## Notes

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All authors have submitted the ICMJE Form for Disclosure of Potential Conflicts of Interest. Conflicts that the editors consider relevant to the content of the manuscript have been disclosed.

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